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HED: Get Real!

DECK: Implementing real-time control schemes offers combined sewer overflow control for complex urban collection systems

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Combined sewer overflow (CSO) is a significant source of pollution in receiving waters. However, implementing a real-time control scheme operates automatic regulators more efficiently to maximize a collection system’s storage, treatment, and transport capacities, reducing the volume and number of CSOs. Real-time control schemes are being used to manage complex urban collection systems around the world, including a demonstration study in Canada for the Quebec Urban Community (QUC) collection system. Funded by the U.S. Environmental Protection Agency (under a contract to the Office of Research and Development) to assess the use of real-time control schemes, the QUC study evaluated the effectiveness of three schemes in managing CSOs.

THE QUEBEC URBAN COMMUNITY TERRITORY DEMONSTRATION SITE

Located on the North shore of the St-Lawrence River, the QUC territory covers 200 mi^2 (500 km^2), has a population of 500 000, and is composed of an Eastern and Western catchment. The QUC study team's evaluation of real-time control schemes focuses on the Western catchment.

The Western catchment covers 65% of the QUC territory, with close to 50% of the total population (230 000). Wastewater is conveyed through 41 mi (66 km) of interceptor pipes to a 82-mgd (310 000-m^3/d) wastewater treatment plant (see Figure 1, p. xx). The collection system has three main interceptor branches and two tunnels that together provide approximately 3.4 MG (13 000 m^3) of inline storage. The overflows of the western collection system represent 528 MG (2 million m^3).

Nine of the 22 regulators have significant overflows that empty into the St-Charles and St-Lawrence rivers. The Dijon, Jones, and Suete CSO structures and the Affluent, and Versant-Sud tunnel regulators overflow into the St-Lawrence River and the Hôpital, Lessard-Durand, Talus, and Myrand CSO structures overflow into the St-Charles River.

The QUC’s long-term CSO control plan is to maximize the Western catchment’s intercepted flow and existing facilities, two inline storage tunnels, and the treatment plant. The long-term plan includes implementing an Optimal Global Predictive (OGP) real-time control scheme in the entire system and constructing offline storage facilities and is projected to control more than 85% of CSOs and cost a total of $107 million, 37% less than before implementing the OGP scheme.

Real-time Control Scheme Simulations

The QUC study team evaluated three real-time control schemes using 32 real rainfall events ranging from very small events to a large once-in-5-year event, as well as back-to-back rainfalls between July 1 and August 28, 1988. Five raingauges collected data to represent, in part, the Western territory’s rainfall heterogeneity. The data then were translated into combined collection system flow rates, which were fed to a custom-built, nonlinear hydraulic model. Using the model and simulation software, a total of 128 simulations were carried out to observe the performance of the three different control schemes. The control schemes were evaluated for CSO volumes, number of CSO events, surcharge occurrence, treatment plant utilization, and inline storage capacity.

Real-time Control Schemes

The study team investigated (1) Local Reactive Control (LRC Type 1) that operates collection system gates at fixed flow set points on the intercepted flow, requiring local site control; (2) Local Reactive Control (LRC Type 2), which works similar to Type 1, except it operates the gates at both fixed and variable set points in respect to flow capacities located at some specific pipes; and (3) OGP that operates the gates at optimal variable set points proactive to actual rainfall conditions, which predicts flow 2 hours in advance using rainguages and flow and rainfall prediction models.

Implementing the LRC Type 1 scheme can be as simple as employing a mechanical device to open or close a system gate while the Type 2 scheme is more complex, similar to the OGP scheme. Both the LRC Type 2 scheme and the OGP scheme require more instrumentation and equipment; however, the OGP scheme differs by using a central decision-making system, prediction models, and other more sophisticated programs and equipment.

Selecting a real-time control scheme depends on the architecture of the collection system and the environmental objectives pursued. Collection systems with small storage capacities, few flow control devices, and restrictive flow constraints can be properly managed with relatively simple control schemes but more complex systems require a global control approach. Selecting a real-time control scheme not only depends on performance, it also depends on criteria such as implementation and process control, capital cost, and operations and maintenance costs.

Control Objectives

Within the Western catchment’s existing collection system (currently without offline retention tanks), the selected real-time control scheme must:

- Reduce CSO frequencies and volume as much as possible during operational season activities (from May 15 to September 15) to meet water quality levels for contact with the St-Charles and St-Lawrence rivers;
- Eliminate surcharge flow caused by flooding from private connections along the inceptor at a setting of 95% of its total capacity;
- Allow variable flow set points to maximize the Western treatment plant’s capacity, which fluctuates with the St-Lawrence River tide; and
- Use the Western system’s two major inline storage tunnels to maximum capacity and ensure no premature

overflows occur while residual storage capacity is available.

Overall Performance

In comparing the three control schemes with one another, the OGP scheme has the lowest CSO volumes and number of CSO events (see Figures 2 and 3, p. xx). Because it can constantly readjust its control set points according to updated field information, this control scheme is the most efficient to control and minimizes the surcharge flow in the system (see Figure 4, p. xx). The OGP scheme also permits programming more sensitive overflow sites as priorities and allows the system to constantly adapt to protect these sites. In fact, the more complex the collection system —— number of flow paths and storage options —— the better the OGP scheme performs.

The difference in total CSO volume between the OGP scheme and LRC Type 2 is relatively small compared to the total CSO volume recorded with the other two control methods. The LRC Type 2 scheme did not eliminate surcharges and is not flexible enough to properly manage future offline storage facilities. The LRC Type 2 scheme is more suitable for controlling relatively simple systems that accept a certain amount of surcharge. At this time, without offline storage tanks, the OGP scheme behaves as a flow management scheme that conveys the maximum amount of water to the Western treatment plant, within the flow constraints.

Using an August 27, 1988 rain event as an example, the inflows to the Western treatment plant without a real-time control scheme and under OGP control show that no overflow occurs at the plant with the OGP scheme (see Figure 5, p. xx). However, without a real-time control scheme, a 0.45-MG (1700-m^3) overflow occurred. The OGP scheme also conveyed 78 MG (295 000 m^3) of combined wastewater to the plant while operating the system with no real-time control scheme only conveyed 72 MG (271 000 m^3) and allowed a 6-Mg (22 700 m^3) overflow at the plant. Furthermore, without a real-time control scheme, the Versant-Sud tunnel was used only as a conveyance system, whereas under the OGP scheme, the tunnel also was used for storage [up to 2-MG (8000-m^3)].

Implementation and Process Control

Implementing either LRC scheme poses more operations and maintenance concerns, depending on the quality and quantity of measurement and control devices installed. To maintain a prescribed flow set point, flow routines must be programmed and calibrated, and controllers, such as Proportional Integrative Derivatives (PIDs) —— mathematical equations used to adjust the position of the system gates —— need to be implemented and properly tuned. Downgraded management modes must be defined and implemented at the local control stations to address equipment breakdowns or other system anomalies and should include predefined flow and gate opening set points for every kind of foreseeable failure or breakdown. Finally, a telecommunication system and a central supervisory control station are recommended to monitor the performance of the control scheme.

The difficulty of implementing the telecommunication system varies with the topography of the territory covered by the collection system. For the Western network, the land is relatively flat, ideal for using a radio telecommunication system. Moreover, the fewer local control stations, the less data traffic to interfere with telecommunications.

Implementing the OGP control scheme requires a more sophisticated level of process control. The difficulties encountered are similar to those described for both LRC schemes. However, design parameters require determining variable measurements and accuracy of the hydraulic model, transmission distortion of control signals, meteorological predictions, and flow set points using optimization (the equivalent to an “intelligent” decision-making machine) and filtering algorithms (such as averaging or exponential computation) and nonlinear programming. In addition, the implementation of a central control station is more complex. An optimal control problem has to be setup and solved in real-time using an optimization algorithm. A meteorological forecasting model, calibrated with raingauge measurements, may be needed to guarantee good performance. If the forecasting algorithm relies on radar images, the availability of these images in real-time must be considered.

Capital Cost

The capital cost of implementing a real-time control scheme depends on the quality and quantity of control and measurement devices required for a successful implementation, as well as the models and the algorithms needed to compute the flow set points. A preliminary study of the Western collection system shows that implementing the OGP scheme costs approximately $4 million (less than 4% the total cost of QUC’s long-term CSO plan), the LRC Type 2 costs approximately $2.5 million, and the LRC Type 1 costs approximately $1.5 million.

Operation and Maintenance Costs

For the Western network, the real-time control schemes are in operation only during the regulated period —— May 15 through September 15, meaning there are no maintenance costs for a significant period of the year.

Operation and maintenance costs depend on the sophistication of the implemented control scheme (the number of control and measurement devices, as well as the geographical characteristics of the collection system). Implementing any one of the three real-time control schemes can be a relatively inexpensive solution compared to conventional alternatives. In fact, in the QUC study each scheme represents less then 4% of the total cost for complying with long term CSO control regulations. Operating the mobile actuators, telecommunication systems, and supervisory systems generate electricity costs and certain models require regular purchases, such as radar images if using a meteorological forecasting model. However, the OGP scheme allows for additional control objectives to minimize electricity costs for pumping and treatment.

Operations and maintenance considerations for implementing any real-time control scheme includes weekly cleaning of sensors, monthly testing of programmable logic controllers and personal computers in downgraded mode, and regular mechanical maintenance of gates and actuators. For implementing the OGP scheme, additional operations and maintenance considerations include calibrating and validating meteorological forecasting model every 3 months. Quality control must be performed on the database processing archives monthly and after each rainfall event. Quality control also must be performed on the collection system configuration every 3 months and after any modifications. The hydraulic models must be calibrated yearly, and statistics and reports on performance and default conditions must be compiled monthly and after each rainfall event. The decision-making system, control objectives, and global and local priorities also must be verified and adjusted monthly and after each rainfall event. Constraints included in the non-linear programming algorithm must be verified and adjusted monthly.

Real Results

The QUC example demonstrates the potential of real-time control schemes in maximizing the capacity of collection systems and reducing CSOs. Even with a relatively simple system with no offline storage to manage, the real-time control schemes evaluated in the QUC reduced CSO volumes by 24% to 47%, representative of potential performance in most collection systems. However, real-time control schemes should be selected depending on a collection system’s configuration and the control and operational objectives specified by the utility authority.

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